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Control of Circular Cylinder Flow by the Use of Dimples

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Measurements are reported of the drag coefficient and Strouhal number of a dimpled circular cylinder over the Reynolds number range from 2×10^4 to 3×10^5. The ratio of the depth of the dimples to the diameter of the cylinder is 9×10^{-3}. In common with sand-roughened cylinders, the dimpled cylinder has a lower critical Reynolds number than a smooth cylinder. After the drag coefficient minimum, the C_D does not rise to the high values that are typical of cylinders with sand roughness but is found to be closer to that for a smooth cylinder. Over a Reynolds number range from about 4×10^4 to 3×10^5, a dimpled circular cylinder has a lower drag coefficient than a smooth cylinder.

Introduction

A CIRCULAR cylinder generates a high mean drag and large fluctuating forces. Over the last 40 years or so a considerable number of investigations have been carried out to study ways of reducing these forces, either by controlling the flow passively or by using some form of active control. Among the passive control devices that have been studied are wake splitter plates[1] and perforated shrouds.[2] The latter device has been used to suppress flow-induced vibration of cylinders caused by the regular shedding of vortices. The fitting of helical strakes[3] is another means of reducing the vibration levels of circular cylinders excited by vortex shedding. However, a major disadvantage of using strakes is that they increase the drag force above the equivalent value for a plain cylinder. This increase is particularly large at postcritical Reynolds numbers. Perforated shrouds are interesting in that they reduce the drag coefficient, relative to a plain cylinder, at subcritical Reynolds numbers but they increase it at postcritical values.

There is a broad range of Reynolds number, spanning the transition between the subcritical and postcritical regimes and stretching far above it, where the flow around a circular cylinder can be influenced significantly by increasing the roughness of its surface. For a cylinder with a smooth surface, placed in a low-turbulence level stream, the start of the drag coefficient fall, marking the beginning of the critical regime, occurs at a Reynolds number of around 3×10^5. At Reynolds numbers below this value, the application of an appropriate degree of surface roughness can be a very effective means of reducing the drag coefficient. However, as shown by Achenbach,[4] the reduction in C_D for a rough cylinder as the Reynolds number is increased through the critical regime is less than that for one with a smooth surface. In general, the rougher the cylinder surface, the lower the value of the critical Reynolds number, but the smaller the fall in C_D through the critical regime. Achenbach also showed that in the high Reynolds number postcritical regime a cylinder with a rough surface finish has a higher drag coefficient than one with a smooth surface.

The flow around a sphere depends on surface roughness in a manner very similar to the way roughness affects the flow around a circular cylinder. As part of an investigation into the aerodynamics of golf balls, Bearman and Harvey[5] compared their measurements of the variation of C_D with Reynolds number for a dimpled golf ball with measurements of Achenbach[6] for spheres with sand-grain roughness. The comparison is reproduced in Fig. 1. Achenbach carried out a series of experiments for spheres with various ratios of the average diameter of the sand grains k to the sphere diameter D. It can be seen from Fig. 1 that, for sand-roughened spheres, increasing k/D reduces the Reynolds number for the drag coefficient fall but that after the minimum the C_D increases rapidly again with increasing Reynolds number. The increased C_D with increased surface roughness in the postcritical regime is thought to be due mainly to the effect of the roughness on the development of the turbulent boundary layer growing on the sphere. Compared with a smooth surface, the roughness causes a thickening of the boundary layer, which leads to an earlier separation of the flow. Equating k to the depth of the dimples on a golf ball, then for a typical golf ball the corresponding value of k/D is 9×10^{-3}. For similar values of k/D, the results in Fig. 1 suggest that dimples cause the C_D to fall at a lower Reynolds number than for a sand-roughened sphere. Also it is evident that after this fall the drag coefficient remains almost constant at about 0.25 for the golf ball, whereas for the sand-roughened sphere it rises sharply after the minimum and asymptotes to a value of about 0.4. Hence, by considering drag coefficient values, it appears that in the postcritical regime the dimples have a more beneficial effect on the flow development than sand roughness.

The present paper describes the results of experiments to assess the effect of dimples on the flow around a circular cylinder as it undergoes transition from subcritical to postcritical flow. The main aim of the investigation was to determine whether dimples can be used to control the flow in the same way as on a sphere. This paper has been prompted by a recent experimental and computational study reported by Kimura and Tsutahara[7] on the effect of spanwise grooves on the flow around a circular cylinder. The width and depth of the grooves, relative to the diameter of the cylinder, were chosen to be similar to the diameter and depth of dimples on a golf ball. In their experiments, which were carried out at a Rey-

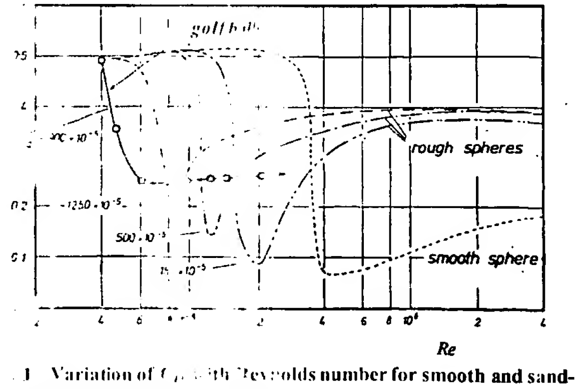

Fig. 1 Variation of C_D with Reynolds number for smooth and sand-roughened spheres and a golf ball.

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